Enhanced Thermal Transport in Nanofluids

SCIENTIFIC ACHIEVEMENT

We have determined that the effective thermal conductivity of liquids can be significantly improved through the dispersion of relatively small quantities of nanoparticles. In the case of ~35 nm diameter CuO or Al_2O_3 nanoparticles, dispersing 4 vol.% nanoparticles results in increases in the thermal conductivity of water or ethylene glycol of up to 20%. Much larger increases are observed for 10 nm diameter Cu nanoparticles dispersed in ethylene glycol, especially if the particle surfaces are treated with thioglycolic acid. In this case, up to 40% improvement in thermal conductivity is seen with the dispersion of only 0.3 vol.% nanoparticles. While our oxide nanoparticle results appear to be in accord with the predictions of a macroscopic theory of heat transfer developed by Hamilton and Crosser [1] for particle-in-fluid systems, we find that Cu nanofluids exhibit anomalously large thermal conductivity. A satisfactory atomic-level theory that explains our observations and provides a predictive capability for other particle-fluid combinations does not yet exist. We have investigated the feasibility of several potential mechanisms, including Brownian motion of the nanoparticles, particle-induced liquid ordering, ballistic heat transport through the nanoparticles, and the effects of possible nanoparticle clustering in the liquid; so far all candidate mechanisms are believed unlikely to account for our observations (*ASME Journal of Heat and Mass Transfer*, **45**, 855, 2002). More recent data on the thermal conductivity of SiO_2-based nanofluids have begun to clearly indicate the importance of the nanoparticle surface treatment. Nanofluids in which SiO_2 nanoparticle surfaces were not treated with surfactants showed thermal conductivity enhancements similar to our earlier CuO or Al_2O_3 nanofluid results, while the use of surfactants with the same SiO_2 nanoparticles resulted in a factor-of-three larger increase in thermal conductivity. Future studies will focus on systematic study of surface treatments, along with the needed development of a theoretical model of nanofluid heat transfer.

[1] R. L. Hamilton and O. K. Crosser, “Thermal Conductivity of Heterogeneous Two-Component Systems,” *Ind. & Engr. Chem. Fund*., **1**, 187-191 (1962).

SIGNIFICANCE

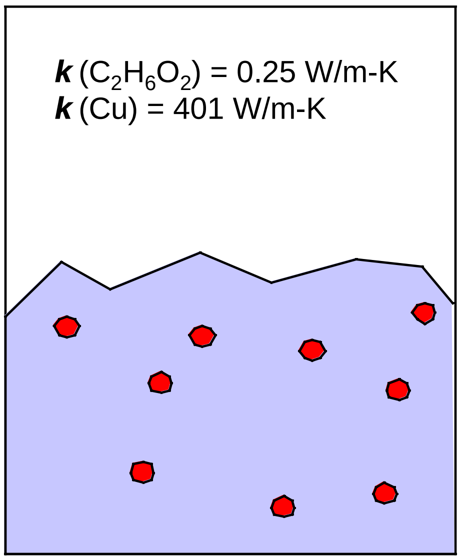
Heating or cooling fluids are of major importance to many industrial sectors, including transportation, energy supply and production, and electronics. The thermal conductivity of these fluids plays a vital role in the development of energy-efficient heat transfer equipment. However, conventional heat transfer fluids have inherently poor heat transfer properties compared to most solids. Despite considerable previous research and development focusing on industrial heat transfer requirements, major improvements in heat transfer capabilities have been lacking. As a result, a clear need exists to develop new strategies for improving the effective heat transfer behavior of conventional heat transfer fluids. Our discovery of the enhanced thermal conductivity of nanofluids is filling this need. Future work identifying the fundamental mechanisms of heat transfer in nanoparticle-fluid systems will provide the basis for the eventual commercialization of nanofluids.

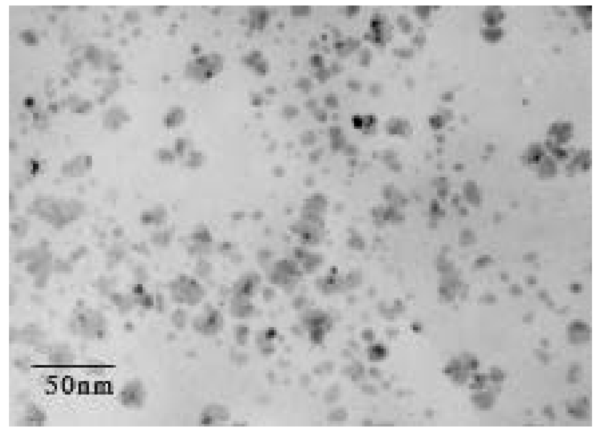
PERFORMER(S)

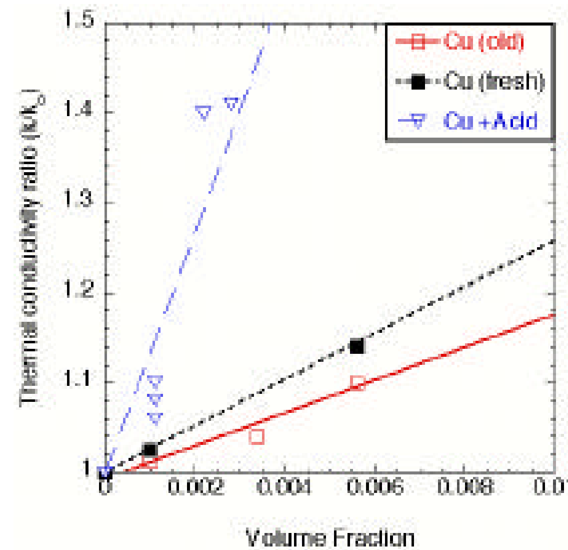
J.A. Eastman, H.-S. Yang, G. Skandan (Nanopowder Enterprises, Inc.), L.J. Thompson, S.U.S. Choi (ANL/ET), S.R. Phillpot, P. Keblinski (RPI)

FWP(S): 58307

Enhanced Thermal Transport in Nanofluids







- Our goal is to enhance the effective fluid thermal conductivity and heat transfer coefficient of liquids by dispersing solid nanoparticles.
- Condensation of copper vapor into ethylene glycol produces ~10 nm diameter copper nanoparticles; other techniques can also be used to produce nanofluids
- The thermal conductivity of ethylene glycol is significantly increased through the dispersion of copper nanoparticles; treating the particle surfaces with thioglycolic acid increases the enhancement

Performers: J.A. Eastman, H.-S. Yang, G. Skandan (Nanopowder Enterprises, Inc.), L.J. Thompson, S.U.S. Choi (ANL/ET), S.R. Phillpot, P. Keblinski (RPI)